B

OPTIMAL DESIGN GUIDELINES

for use on

OVERHEAD & UNDERGROUND SYSTEMS

In the

NSTAR DISTRIBUTION SYSTEM

April 2004

INDEX

Capacity
Settings
Reverse Flow

C. Capacitors

Power factor correction
Voltage correction
Remote control

D. Protective Devices

Station breaker
Reclosers
Sectionalizers
Automatic Sectionalizing Units (ASUs)
Fuses

III. UNDERGROUND EQUIPMENT

A. Conduit Systems

Manholes
Duct banks

IV. SECONDARY VOLTAGE SYSTEMS

A. Single Phase

Overhead
Underground
Network

B. Three Phase

Overhead
Underground

C. Split Fiber Mains

Existing systems
Replacement method

V. URD & UCD SYSTEMS

A. Underground Residential Development (URD)

Direct Buried Installations
Conduit Systems
Primary Cables
Secondary Cables
Transformers
Switches
Other equipment
Apartment Buildings

B. Underground Commercial Development (UCD)

- Direct Buried Installations
- Conduit Systems
- Primary Cables
- Transformers
- Switches
- Other equipment

VI. PRIMARY VOLTAGE SERVICES

A. Customer Stations

- Loop stations
- Main-tie-main
- Primary selective
  - Breakers
  - Loadbreak & Power fuses

B. Company Installations

- Single Customer (SC) Installations
- Multiple Customer (MC) Installations
- Spot Networks

VII. DISTRIBUTION SUPPLY SYSTEMS (DSS LINES)

A. Function of a DSS Line

B. Function of a Line Group

C. Types of Load Served

- Load Center Units (LCUs)
- Primary Network Units (PNUs)
- Customer Stations, SCs, MCs
- Spot Networks
- Distribution Circuits
- Inter-station Ties

D. Loading Considerations

- Normal Configuration
- Contingency (N-1) Configuration

E. Construction Types

- Cable and Wires
- Recloser Applications
- Switches Used

F. Protection and Relaying

- Radial Lines
- Distribution Circuit Taps
- Looped Customer Stations

G. Numbering Scheme

- Radial Lines

Primary Network Feeders
Non-Source Lines

VIII. NETWORK SUPPLIES

A. Feeder Design
B. Feeder Loading
C. Secondary Mains and Services
D. Secondary Network Vaults (SNVs)
  Public Way Units
  Private Property Units
  Transformers & Protectors
E. Tertiary Network vaults
  Normal Configuration
  Contingency (N-1) Configuration
F. Remote Monitoring Systems
G. Protection and Relaying
H. Numbering Scheme

IX. IMPROVEMENT SYSTEMS & PROGRAMS

A. Cable Cure
B. Cable Wise
C. Circuit Walkdowns
D. Infrared Surveys

I. OVERHEAD & UNDERGROUND RADIAL SYSTEMS

A. 4 kV System

Expansion Limitation

Load additions of no greater than 300 kVA are to be installed on 4kV circuits. In areas where 14kV supply is available as an alternative to 4kV supply, consideration should be given to supplying the new loads via 14kV. Any new construction or system rebuilds in 4kV overhead areas should be built for 14kV operation.

Underground Construction

Underground 5 kV Cables

- #2 Cu 15kV and #1 Al 15kV cable for taps to transformer manholes
- 4/0 Cu 5kV cable for large taps off the main line of a circuit
- 500 Cu 5kV cable for circuit feeder sections

Underground 5 kV Transformers

- Single PhaseTransformers
  - 100 kVA 120/240 Volt fused type
- Three Phase Transformers
  - 112.5 kVA 240X480 Volt
  - 112.5 kVA 120/208 Volt
  - 225 kVA 120/208 Volt

Underground 5 kV Switches

Sectionalizing switches are to be installed for every 500 kVA of connected transformation. When additional or replacement switches are required either a G & W Trident switch with interrupter or a G & W Trident switch without interrupter can be used. Follow the switch placement guidelines below.

Types of Switches

The following is a brief description of the switches that are either in use or can be used in manholes on the underground 5 kV system.
The following two switches are the **only options for installation at this time**:

G&W Trident Switch (with interrupter): This is the switch to be used in ASU type installations. They should NOT be installed without the approval of the Relay Protection Group through the System Engineering Group. The installation of these switches as ASUs is limited to locations where the fault duty is less than 12,500 amperes. In addition, the switches cannot be operated in series other than in off schedule conditions. The standard installation is at the midpoint of the 4 kV circuit and as a tie switch.

G&W Trident Switch (without interrupter): This switch is identical to the ASU switch but without the interrupter. It has all the same physical characteristics. This is the new standard switch that is to be used as a replacement switch for the Phoenix or Elastimold switch or in new installations. This switch and the ASU switch are elbow connected and motor operated switches. This switch can be installed in any locations where the fault duty is less than 20,000 amps.

The following two switches are currently in use but **no longer installed:**

Phoenix switch: This is the oil insulated switch that was installed throughout the Boston Edison System for decades. The switch is no longer purchased or installed. In existing locations any Phoenix switch that is encountered in a work area has been or should be retrofit to enable operation under load. If the switch cannot be retrofit, it cannot be operated under load.

Elastimold switch: This is the original replacement switch that was used when the decision was first made to stop installing the Phoenix oil switch. It is a vacuum insulated switch with 600 ampere elbow connections that is operated from above the manhole with a stick. The use of this switch has also been discontinued.

Overhead Construction

New 4kV overhead construction is to be open wire build for 14kV operation. The transformers and the mainline primary taps are to be fused.

Overhead 5kV Wires

- 1/0 Al 15 kV Open wire and Spacer cable (used for tree areas)
- 336 Al 15 kV Open wire and Spacer cable (used for tree areas)

Overhead 5kV Transformers

- Single PhaseTransformers
  - 25 kVA 120/240 Volt Dual Ratio (7.9kV/4.16kV)
  - 37.5 kVA 120/240 Volt Dual Ratio
  - 50 kVA 120/240 Volt Dual Ratio
  - 100 kVA 120/240 Volt Dual Ratio (Use should be limited)
- Three Phase Transformers
  - 45 kVA 240 Volt Dual Ratio
  - 45 kVA 120/208 Volt Dual Ratio
  - 112.5 kVA 240 Volt Dual Ratio
  - 112.5 kVA 120/208 Volt Dual Ratio
  - 150 kVA 120/208 Volt Dual Ratio
  - 150 kVA 277/480 Volt Dual Ratio
  - 150 kVA 240 Volt 4.16kV
  - 150 kVA 480 Volt 4.16kV

Overhead 5kV Switches
Sectionalizing switches are to be installed for every 500 kVA of connected transformation. New installations should be 600 Amp 15kV Load break units

B. 13.8 kV System

Open Loop System: A higher level of reliability is achieved with a loop system. The Primary Loop shall be able to be isolated, without interruption, and the outage duration of a fault is reduced to the time it takes to find it and do the necessary switching to restore service to the rest of the circuit. This switching can be done either manually or automatically through the ASU. When building a loop system we must take into account the needed capacity of both circuits to be carried by one circuit. Open loop systems are installed between different substations distribution circuits while others are within their station distribution circuits.

Underground Construction:

- Cables: All cables shall be cross-linked polyethylene insulated with a concentric neutral, and be rated for 15kV. The feeder section of the distribution circuit shall be 700MCM, the main line – 500MCM or 250MCM, Distributors - #2Cu or #1Al

- Transformers are either padmounted or submersible. Padmounted transformers are looped and fused using dead front transformers fused internally. They are available in sizes ranging from 112.5kVA through 2500kVA for three phase and from 25kVA through 167kVA for single phase. The submersible transformers are also looped and fused and are available in sizes ranging from 150kVA through 1000kVA for three phase and from 25kVA through 167kVA for single phase.

- Switches

  15kV manual PME-9 switch –
  This switch cannot be converted to a radio controlled switch. It has two 600 ampere connections and two 200A fused connections that accept 100C fuses.

  15kV radio controlled PME-9 switch –
  This switch is similar to the manual switch but has fault indicators which return fault indicator to SCADA. It has an automatic throwover function with a transfer time of approximately 8 seconds. It has two 600 ampere connections and two 200A fused connections that accept 100C fuses.

  15kV radio controlled Micro-AT switch –
  This is a radio controlled switch installed with fault indicators which return fault indicator to SCADA along with an automatic throwover function with a transfer time of approximately 10 cycles using a spring charged mechanism. It has two 600 ampere connections and two 200A fused connections that accept 100C fuses.

15kV manual padmount switch-
This is a manual switch that cannot be converted to a radio controlled switch. It has two 600 ampere connections and 2 vacuum interrupters. This switch is used where clearances cannot be obtained to install and operate a manual PME-9 switch.

Overhead Construction

- Wires

  Standard Construction - Open wire construction with 8 foot crossarms is still the Company standard and should be used wherever tree clearances are not an issue.

  Short Arm Construction - The new open wire construction with 44 inch crossarms should be used where there are (moderate) tree conditions but proper clearances can still be achieved.

  Spacer Cable - This type of construction should still be used in heavily treed areas or when there is already an existing circuit on the pole line.

  Armless Construction - This is often used in the City of Boston. This type of construction should not be used because it cannot endure icing conditions and the insulators that are used have been subject to premature failures.

  All O.H wire shall be 336Al or 1/0Al ACSR or Spacer

- Transformers
  All O.H. Transformers shall be individually fused.
  Available O.H. Transformers for single phase are 37.5, 50, 100 and 167kVA.
  Available O.H. Transformers for three phase are 45, 75, 112.5, 150 and 300kVA.
  NSTAR no longer installs 300kVA transformers on the O.H. unless it is a replacement for an existing 300kVA
  Mat type Transformers are to be used only for replacement of existing Mat type

- Switches
  Load Break Switch – Manual operated
  SCADAMATE Switch – Radio controlled
  ASU – Auto sectionalizing unit with or without SCADA control
  Recloser – used on location requiring greater then 100K Fuses
  Fuses – Ranging from 6K to 100K

  Each circuit shall have at least 2 ASU switches, one at the midpoint of the circuit (normally closed) the other as a tie to a different circuit (normally open).
  There shall be a radio controlled switch every 3,000kVA or 1,500 customers and manual switches every 1,000kVA or 500 customers

All laterals to be fused in accordance to the connected load. Open Loop System

C. 24 kV System

General: Construction of all overhead and underground distribution systems will be designed in accordance with currently approved construction standards and materials. Maintenance methods and worker safety considerations shall be of primary concern in design decisions. All new system facilities' construction and replacements, both overhead and underground, should allow for a supply from a grounded wye source, and be in compliance with the present revision of the NESC and all other applicable municipal and State codes.

Underground Construction: Typical 25kV underground system applications are for underground residential developments (URD's) and underground commercial developments (UCD's) supplied from the overhead. See separate items outlining these guidelines. The following applies to 25kV underground main line construction.

- Cables: Conductor sizing will be in accordance with applicable construction standards normal and emergency loading criteria. All new underground installations require cables to be in a manhole and duct system. Ducts should be encased in concrete. 25kV cable sizes used for new main line applications are 500kcmil Al, 500kcmil Cu, 1000kcmil Al, 1250kcmil Al, and 1250kcmil Cu.
- Transformers: Transformers are typically not installed within 25kV underground main line areas.
- Switches: Switching devices in the underground are typically not installed within 25kV underground main line areas. Pad mounted switches can be used, and these designs are outlined under the separate URD & UCD guidelines. At certain locations, dead break elbows are installed in manholes within an underground main line. Station and/or overhead switching are performed in the event these elbows need to be utilized.

Overhead Construction: Construction shall meet, at a minimum, NESC Class C requirements. Construction on rights of way generally shall meet NESC Class B requirements. Lateral taps off the main line & main line equipment will have fused cutouts applied and coordinated to prevent burn down and minimize the extent and duration of customer outages. Type "T" fuse links are used with 25kV construction, except Type "K" fuse links are used for capacitors.

- Wires: Conductor sizing will be in accordance with applicable construction standards normal and emergency loading criteria. 25kV wire sizes used for new replacement/installations are:

Phase Conductor	Minimum Neutral
795kcmil Al	3/0 Al
795kcmil Al Spacer	1/0 Al
477kcmil Al	3/0 Al New Construction or 1/0 Al rebuild
477kcmil Al Spacer	1/0 Al
4/0 Al Spacer	1/0 Al

3/0 Al	1/0 Al
1/0 Al	1/0 Al

Circuit main line primary conductors will be a minimum of 3/0 Al. Distribution supply main line primary conductors will be a minimum of 795kcmil Al. Lateral primary conductors will be a minimum of 1/0 Al. Primary conductor covering will be considered in areas of extensive tree exposure and in areas where conductor spacing is less than specified for the particular voltage. The use of spacer cable may be considered for special applications involving safety, aesthetics, space availability, tree conditions, reliability, and for dedicated feeder circuits.

- Transformers: Selection of individual transformer phase connections will be determined by Engineering to control the balance of circuit-connected kVA. Single phase lateral phasing will be controlled in the same manner. Existing transformer loading will be studied when additional loading is contemplated. The decisions concerning combining or splitting loads, and the sizing and location of transformers will be based on studies of optimum transformer loading and minimize voltage drop. A transformer load management tool (TLM) is utilized and checked, as well as actual customer billing information, to monitor & determine transformer upgrades. To provide for 3-phase, 4 wire secondary customer voltages, single-phase transformers will be installed in an overhead cluster mount banked configuration and connected appropriately.
- Single phase 120/240V and 277V secondary transformer sizes: 15kVA, 25kVA, 25kVA with extra creep bushings for coastal zones, 37.5kVA, 50kVA, 50kVA with extra creep bushings for coastal zones, 75kVA, 100kVA, and 167kVA.

- Step down transformers may be used to lower the voltage from 25kV when an area is susceptible to salt spray and mist, among other applications. 3-phase secondary step down voltages from 3-phase primary 25kV include 4.16kV wye, 4.8kV delta, and 8.32kV wye configurations. The maximum 3-phase kVA of a cluster-mounted bank on a pole will be 750 (3-250kVA). See step down transformer section for more information.
- Switches: New distribution circuit switches employed for disconnecting or transferring the total or major portion of the circuit load to alternate sources will be 3-phase, gang operated load break devices. Auto sectionalizing units (ASU's) with remote operation capability have recently begun to be installed on the 25kV system. Single phase switching will be avoided, especially when large blocks of industrial and commercial loads are involved. 1200Amp switches will be used on the 25kV distribution supply lines and 600Amp switches will be used on the 25kV circuits. Line cutouts may be used for switching in areas where 3-phase switching is not deemed imperative as above. Underslung type disconnects may be used for sectionalizing points, equipment disconnects and bypasses, but not for switching 3-phase load or tying circuits. Recloser installations shall include single-phase line disconnecting devices on the line side and the load side of the recloser. The installation should include bypass devices on radial circuits.

II. OVERHEAD EQUIPMENT

A. Step-down transformers

Three phase
Three phase step-down transformers are used sparingly and only installed in special cases where it is difficult to convert a small area of three phase load.

Single phase - two bushing
Delta-wye transformers are no longer installed on new installations. We will not install reclosers to the existing delta-wye installations that currently do not have reclosers for protection against single phasing. If a delta-wye transformer fails in service and it does not have a recloser, we will replace the 3 delta-wyes with 3 wye-wye transformers. If a delta-wye transformer fails in service and it does have a recloser, we will replace that unit like for like.
The source side of both 333 and 500 kVA step-downs will be fused with 2-40K fuses per step-down on the source side.

Single phase - single bushing
All new installations will use single phase - single bushing transformers. The transformers will not be loaded over the full nameplate rating in normal or contingency conditions.

The source side of both 333 and 500 kVA step-downs will be fused with 1-80K fuse on the source side. The operating practice will be "break before make" where there is a delta-wye bank tie to a wye-wye bank.

B. Voltage Regulators

Applications
Single phase voltage regulators are used on overhead distribution where the load and distance are large enough that proper voltage cannot be maintained along the circuit. They are also used where the station transformers are not equipped with automatic tap changing to regulate under load.

Capacity
The standard sizes in use on the 13.8 kV system are 167 KVA and 250 KVA. Smaller units of various sizes are in use along the 4 kV system, however, the standard size is 75 KVA.

Settings
Regulator are set to maintain voltage at the end of the circuit or at the first load beyond the regulator using standard line drop compensator calculations.

Reverse Flow
All 13.8 kV regulators currently being purchased are reverse flow regulators that allow the passing of load current in either direction.

C. Capacitors

Power factor correction
Capacitors are used on the 13.8 kV system for power factor correction for bulk stations. They are applied along the circuits with base, intermediate and peak schedules to allow for power factor correction at various load levels.

Voltage correction
Capacitors are often used on the 4 kV system (and sometimes on the 13.8 kV system) to improve voltage regulation. All 4 kV capacitors use time clock controls.

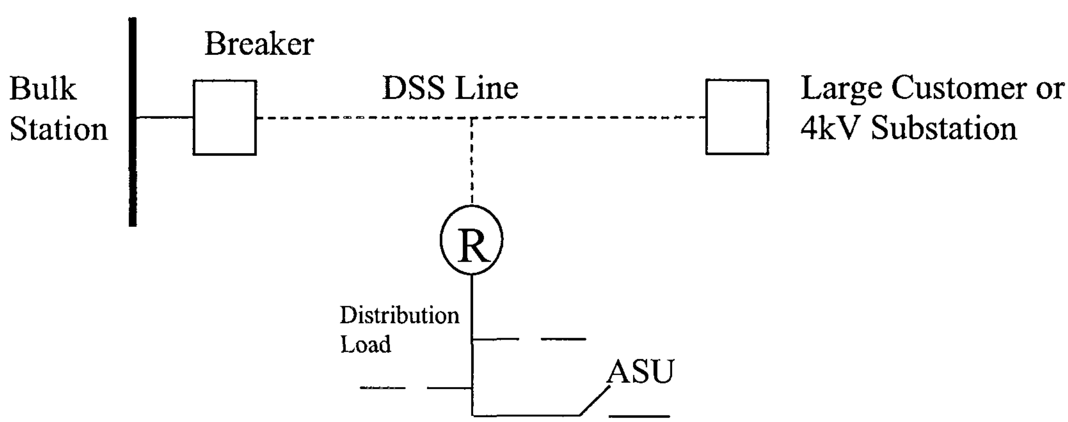
Remote control
All capacitor banks on the 13.8 kV system are installed with radio controls to allow for systematic loading by the dispatch center.

D. Protective Devices

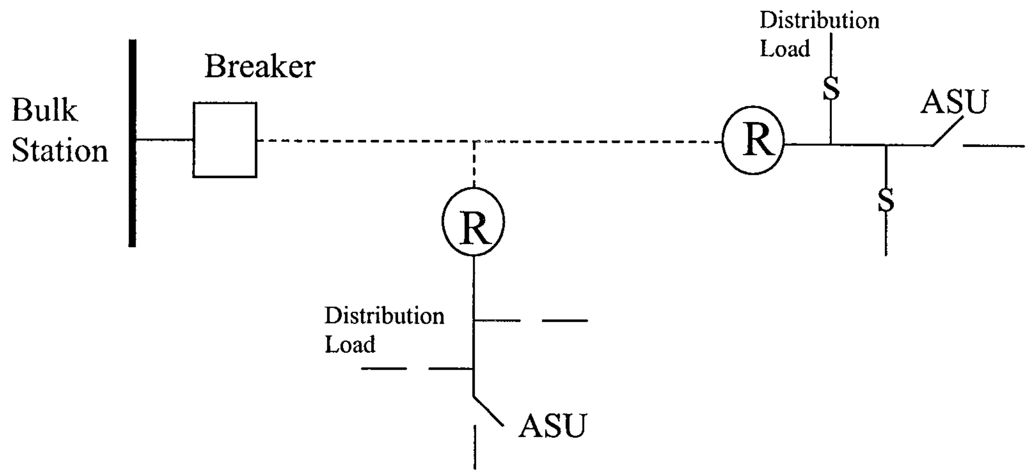
Station breaker
All circuits should be protected by a station breaker at the source station.

Reclosers
The following is a summary of the recloser installations that should be used:

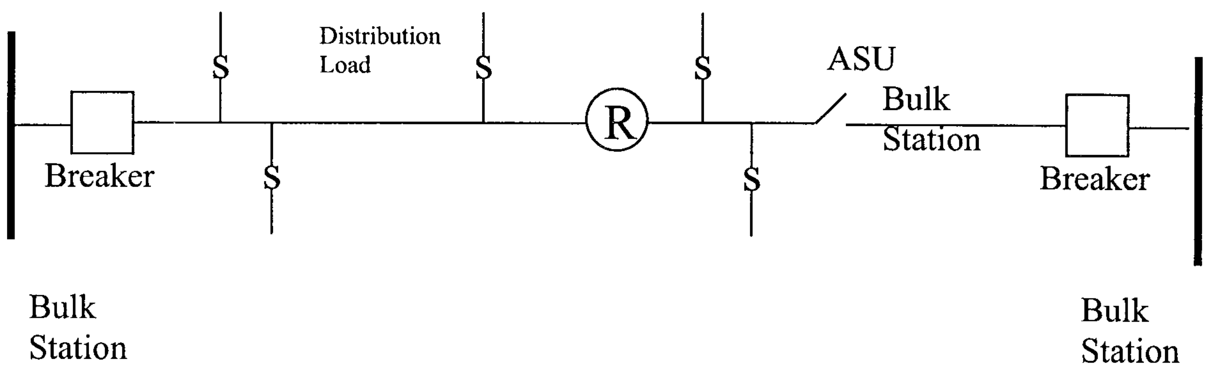
- This design is used when tapping a D.S.S. Line. In the case of a fault within the Distribution Load, the Recloser will operate in order to maintain the integrity of the D.S.S. Line.



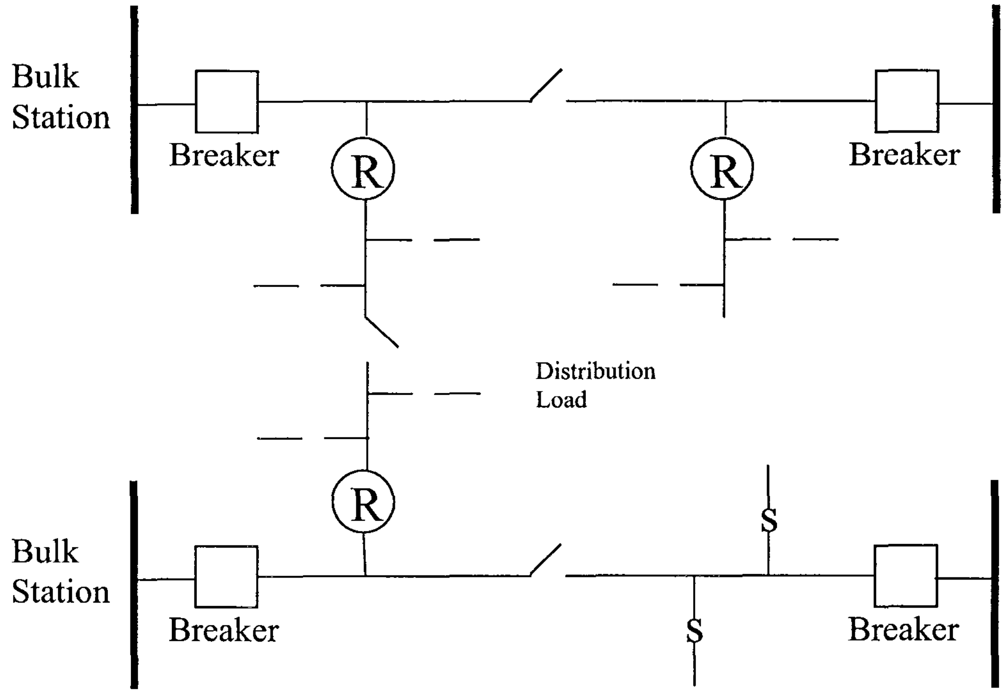
- Typical installation of two Reclosers when a Distribution circuit is bifurcated and we are not able to maintain reclosing at the Station. If reclosing can be maintained at the Station, pole mounted recloser will be replaced with an ASU if the recloser fails. Otherwise the recloser will be replaced by another recloser.



- This design is used when the fault current is too low and the station breaker is unable to pick it up due to the length of the circuit.



- The basic design application for reclosers is to tap a station to station Distribution Supply line to feed an area based on the criteria of load, number of customers and distance of line. All lateral taps are fused or sectionalizers may also be employed at certain T-NODES depending on load, number of customers and distance of line. Radial applications are similar however, fuses are used on the mainline.



Sectionalizers

Sectionalizers were commonly used where loads were too large to install fuses but a protective device was required. These devices work as disconnecting devices but do not interrupt load. They are programmed to open after a recloser or station breaker has opened to de-energize the circuit.

Automatic Sectionalizing Units (ASUs)

These are radio controlled devices that operate like sectionalizers, however, they are loadbreak devices and can be used to make or break load.

Fuses

Fuses are used throughout the system to protect the circuit backbone as follows:

- On single or three phase transformers connected to the circuit backbone.
- On single or three phase side taps.
- On single or three phase primary risers.

Fuses are sized based on the connected KVA and the ability to withstand cold load pickup.

III. UNDERGROUND EQUIPMENT

A. Conduit Systems

Manholes

- 4'X4'X6' For secondary use only – Used for SFM conversions
- 4'X6'X8' For secondary use and primary taps – Used for SFM conversions
- 6'X10'X8' Standard line manhole – Existing manholes can be adapted for transformer installation
- 6'X10X10' Standard line manhole - Existing manholes can be adapted for transformer installation
- 10'X13'X10'X10' Triangular manhole (Getaway/intersection manhole)
- Modified HA 300 6.5'X12.5'X10', Used for underground transformers

Duct banks

- 2-4" EB encased in concrete – Standard between manhole and padmounted transformer
- 2-5" EB encased in concrete – Standard between manhole and pole
- 4-5" EB encased in concrete
- 6-5" EB encased in concrete – Standard between mainline and equipment manhole
- 9-5" EB encased in concrete – Standard mainline duct bank
- 9-6" EB encased in concrete – Used where possible in station getaways.
- 12-5" EB encased in concrete – Limited use only

IV. SECONDARY VOLTAGE SYSTEMS

A. Single Phase

Overhead:
Wire size: 3x 2 al, 3x 1/0 al, 3 x 3/0 al
The nominal design is to install 3x3/0 al radial secondary mains from pole to pole with single phase transformers located on street poles. Single phase overhead transformer sizes are as follows: 37.5 kVA, 50 kVA and 100 kVA. The loading on the transformers should be design to be below the transformer load rating. If possible, secondary wire breakers are located in the overhead mains between transformers. These wires can then be connected in order to pick up load in case of transformer failure.

Underground
Cable size: 3-#4, 2-1/0 &1-#4, 2-4/0 and 1-1/0, 2-350 and 1-4/0, 2-500 and 1-350.
The nominal design is to install cables in an underground duct system, usually 3 ½ or 4 in. pipe, from manhole to manhole in the public way. Multiple sets of secondary cables are connected to a transformer or group of transformers and installed radially from the transformers to supply the secondary mains. The load they supply determines the size of the main. Single-phase transformers are as follows: 50 kVA, 100 kVA, and 167kVa.

Network- 120/208v
Cable size: 3-#4, 3-4/0
This is not a normal secondary voltage system in the street. It is supplied from a 3 phase 4 wire secondary main and used to supply a small customer load not greater than 200 amperes.

B. Three Phase

Overhead-240v, 480v, 120/208v, 277/480v
Wire size: 4x1/0, 4x3/0, 3-350, 3-500
The nominal design is to have a 240v 3 phase transformer mounted on a pole in the public way and to install radially 4x3/0 al. secondary mains from pole to pole. These transformers are generally placed to supply specific loads and do not have secondary breakers installed between them.
A transformer on a private property pole to service a particular customer load usually supplies 480v, 120/208v and 277/480v system requirements. They are not normal street voltages. The customer's load would determine secondary service wire size and number of conductors.

Underground
Radial- 240v, 480v, 120/208v, 277/480v
Cable size: 3-4/0, 3-350, 3-500
The nominal design is to install 240v 3 phase cables in an underground duct system, usually 3 ½ or 4 in. pipe, from manhole to manhole in the public way. Multiple sets of

secondary cables are connected to the 3 phase transformers. These mains supply specific loads and do not have back-up supplies.

A transformer in a private property manhole would be required to service a customer load at 480 volts 120/208 volts or 277/480 volts. These are not nominal street voltages. The customer's load would determine the service cable size.

Network- 120/208, 277/480v

Cable size: 7-4/0, 4-350, 4-500

The network secondary design is to install multiple sets of 7-4/0 cables in an underground duct system, usually 3 ½ or 4 in. pipe, from manhole to manhole in the public way in the form of a grid. Numerous transformers in Secondary Network Vaults supplied by different sources supply this grid of secondary mains. Cable limiters that protect the cables from overheating protect these secondary mains. The normal street voltage is 120/208v, 3phase, 4 wire. Voltage at 277/480v, 3 phase, 4 wire, is not a street voltage and is used to supply individual customers requirements.

C. Split Fiber Mains

Existing system:

The existing Split fiber main (SFM) is a direct buried, 120/240v secondary voltage system, which was installed between 1910 and 1960. The split fiber main system was constructed using sections of half-pipe (cut longitudinally), 2 inch x 6-inch sections of wooden plank, field constructed wooden boxes, and a tar-like low-tension compound. The SFM service consists of two 4/0 cables and one 1/0 cable, placed into the half-pipe, secured with the tar-like compound and covered with the 2inch x 6inch wooden plank. Wooden junction boxes were installed where customer service cables splice into the main secondary service. These splice boxes are also filled and covered with the tar-like compound. From the wooden splice box, the customer service cables route directly into the customer's building through a service pipe. Single phase transformers are located in various manholes in the primary system, which provide service to the SFM secondary system.

Replacement method:

The replacement of the SFM system requires the installation of 4ft x 4ft x 6 ft manholes and a duct system using two 4 inch pipes. The new secondary cable system, consisting of two 500 and one 350, 600v cable, is installed in these ducts. New service pipes are then installed from the manholes to the customers existing service locations. New service cables, two #4 cables and a #4 bare, are installed from the manholes to the customer's service locations. Larger size cables, 2-1/0 and #4 bare, are installed if the customer's load requires them. Existing transformer loads and connections are reviewed to determine if these transformers can be utilized to supply the new secondary main system.

V. URD & UCD SYSTEMS

A. Underground Residential Development (URD)

Direct Buried Installations
Underground Residential Development installations were originally installed with direct buried primary and secondary cable systems. These installations began in the early sixties and consisted of installing the cables in trenches, without conduit or pipe, as the new streets were being developed. These systems are now all installed in conduit systems.

Conduit Systems:
The conduit system consists of schedule 40, 4 inch pipes installed from pole to transformer, from transformer to transformer, from transformer to switching stations and from transformers to handholes. 4 inch conduit is also used for secondary cable installations. If 500mcm primary cable is to be used, 5 inch pipe is used for he primary cable

Primary Cables:
The primary cable used is #2 al or 500MCM 15kv xlpe cable. The number of phases is determined by the connected transformation and primary voltage.

Secondary Cables:
Secondary cable in a URD is 3 x 3/0 al. 600v al. cable. These cables are installed from the transformers to the handholes on the customer's lot. If the transformer is located on the customer's lot, the customer installs the secondary cables from the service location to the transformer.

Transformers: Transformers installed in URD are all padmounted deadfront transformers. Typical single phase sizes are: 25KVA, 50 kVA and 100kVA. Three phase transformers are installed if necessary. The location of the transformer is usually governed by the estimated customer demand and length of secondary service.

Switches: All switches in an URD are padmounted switches. They consist of 600 amp switches with fused taps. These switches are used when the 3 phase demand in an URD is over 2000 kVA. For loads less than 2000 kVA, 3 phase above ground cable switching stations may be used.

Other equipment: Fiberglass pads are used for single phase transformers, switchgear and switching stations and also may be used as splice boxes and pull boxes.

Apartment Buildings: Most apartment building URD installations consists of 3 phase loads. Three phase dead-front transformers are installed on pads constructed by the customer. Primary cable is installed in conduit as in a regular URD development. However, all secondary cables are furnished and installed by the customer.

B. Underground Commercial Development (UCD)

Direct Buried Installations: No direct buried cable systems are installed. All cable is installed in conduit.

Conduit Systems: The conduit system consists of schedule 40, 5 inch pipes installed to all pads, transformers, manholes and switching stations.

Primary Cables: The primary cables consist of 500 mcm 15 kV cable used for main circuit backbone and #2 15kV al. used for taps to supply transformers.

Transformers: Most transformers are 3phase deadfront pad mounted transformers – size determined by the customers load.

Switches: 600 amp Padmounted switches with 200 amp taps are installed as necessary to sectionalize the load in 2000kva of less sections.

Other equipment

The guidelines for the installation of our Underground Residential Distribution System are outlined in Construction Standard 2.10 – 10.3. The standard contains guidelines for determining the size and number of conduits, installation of the conduit and cable, and suggested pulling distances, for several conduit and cable combinations.

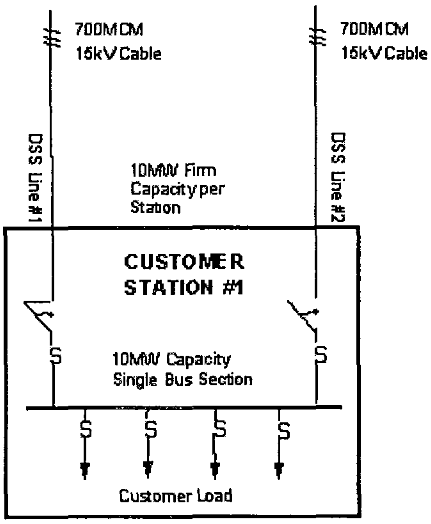
VI. PRIMARY VOLTAGE SERVICES

A. Customer Stations

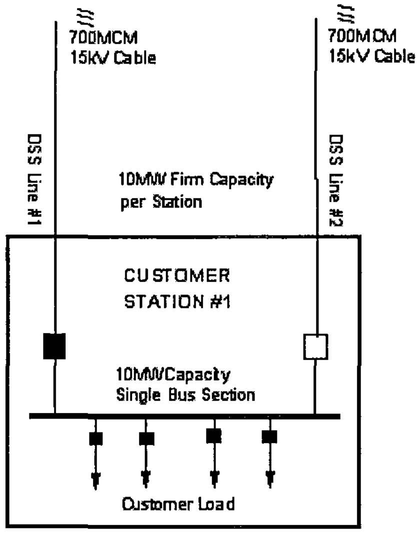
Loading and customer requirements dictate the use of customer stations as described:

- Loads under 10 MW may be fed by two DSS or radial lines (may have auto-transfer)

  ⇒ Option 1: One NC loadbreak and power fuse; one NO loadbreak and power fuse; each DSS line has a firm capacity of 10 MW

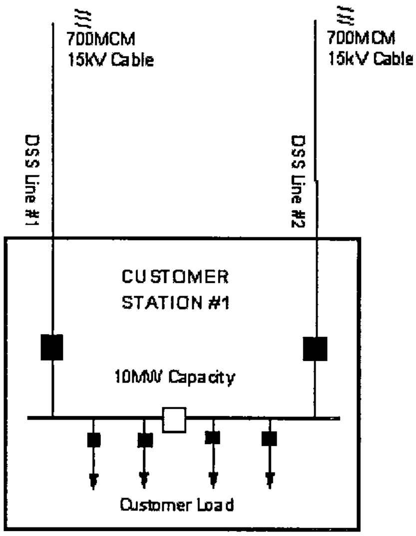


  ⇒ Option 2: One NC breaker; one NO breaker; each DSS line has a firm capacity of 10 MW



700MCM
15kV Cable
700MCM
15kV Cable
DSS Line #1
DSS Line #2
10MW Firm Capacity
per Station
CUSTOMER
STATION #1
10MWCapacity
Single Bus Section
Customer Load

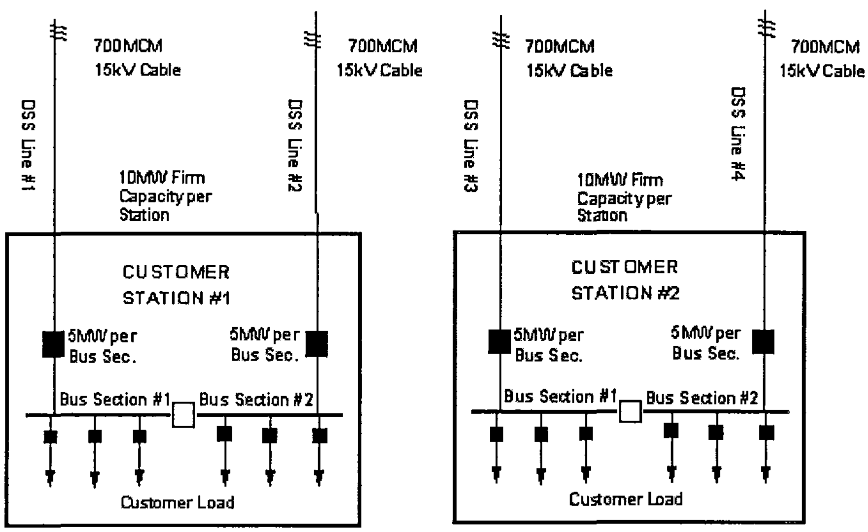
⇒ Option 3: Main-tie-main



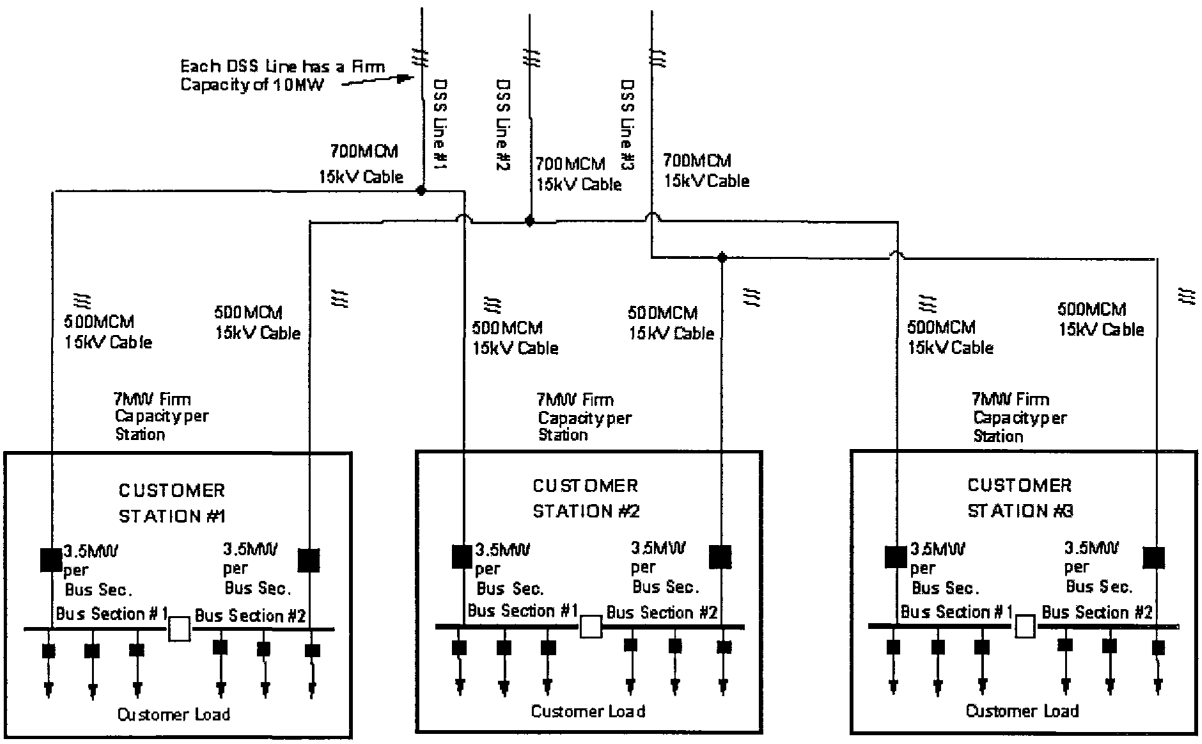
- Loads over 10 MW generally fed by multiple customer stations

$$\left(\text{Stations Required} = \frac{\text{Total MW}}{10} + 1 \right)$$

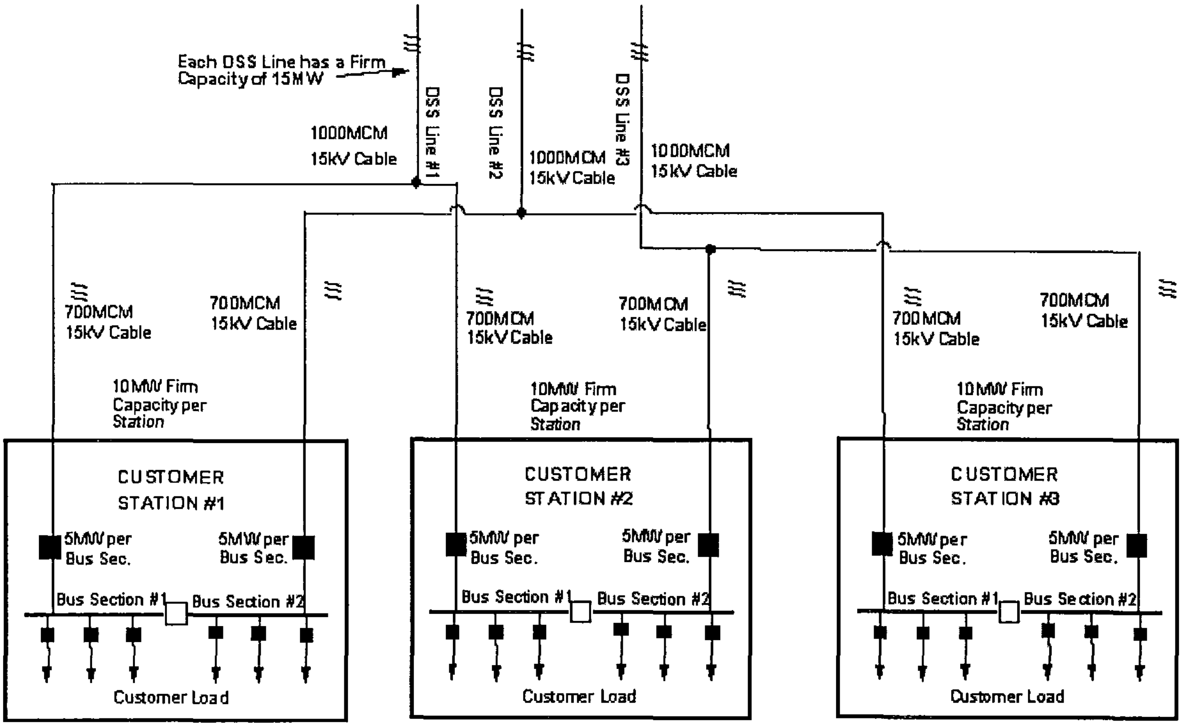
⇒ Option 1: Two pairs of DSS lines feed two customer stations (one pair per station); each station contains two sections of switchgear with a normally open bus tie. Customer to follow IEEE 519 publication in regards to Harmonic Distortion.



⇒ Option 2: Multiple DSS lines (firm capacity of 10 MW each) feed customer stations, with each station having a total capacity of approximately 7 MW. Two DSS lines are required for each customer station. Customer stations have two sections of switchgear and an open bus tie. Customer to follow IEEE 519 publication in regards to Harmonic Distortion.



⇒ Option 3: Multiple DSS lines (firm capacity of 15 MW each) feed customer stations, with each station having a total capacity of approximately 10 MW. Two DSS lines are required for each customer station. Customer stations have two sections of switchgear and an open bus tie. Customer to follow IEEE 519 publication in regards to Harmonic Distortion.



- Loop stations – Two DSS lines feed station via normally closed breakers. Should one line fail, the other line will carry the entire station load.
  - Used when greater reliability is desired (over radial systems)
  - Loop must meet all power and voltage drop requirements when fed from either end
  - Larger conductor size required to avoid unacceptable voltage drops when fed from only one end

B. Company Installations

Single and Multiple Customer (SC/MC) Installations - These are private property installations using switchgear with loadbreak switches and power fuses. In the case of the SCs and MCs, the switchgear is purchased and maintained by the Company. For the customer stations, the switchgear is purchased and maintained by the customer.

Spot Networks - These are installations with transformers and protectors networked on the secondary voltage level. This type of installation should be used where the area is likely to become part of a secondary network supply. Power flow between any two points is usually split among several paths, and if a failure occurs, power is instantly and automatically re-routed.

VII. DISTRIBUTION SUPPLY SYSTEMS (DSS LINES)

A. Function of a DSS Line

A DSS line is a line typically used to supply non-distribution load such as customer stations, spot networks or load center units. It usually does not supply distribution load directly but may supply distribution load through a recloser or padmounted switch with fuses or interrupters.

B. Function of a Line Group

A Line Group is a series of two or more DSS lines that supply a common load or group of loads. A typical line group is designed so that the remaining lines can supply all of the load of the line group under the worst single contingency condition without any of the remaining lines exceeding their LTE rating.

C. Types of Load Served

DSS Line Groups are used to supply the following types of loads:

- Load Center Units (LCUs) – These are 14kV to 4 kV or 24 kV to 4 kV stations that supply the 4 kV distribution system. In the Boston Edison System they typically have two or more transformers and two or more bus sections. In the Commonwealth Electric and Cambridge Electric Systems they typically have only one transformer.
- Primary Network Units (PNUs) – These are single transformer 14 kV to 4 kV installations located within an area to supply a primary network. The 4 kV distribution circuits are solidly connected from one PNU to another in order to withstand a DSS line outage without customer outage. There are three networks in existence (Brookline, Somerville, Roxbury) that are being systematically eliminated through conversion to 14 kV.
- Customer Stations, SCs, MCs – These are private property installations using switchgear with either loadbreak and power fuses or breakers. In the case of the SCs and MCs, the switchgear is purchased and maintained by the Company. For the customer stations, the switchgear is purchased and maintained by the customer.
- Spot Networks - These are installations with transformers and protectors networked on the secondary voltage level. This type of installation should be used where the area is likely to become part of a secondary network supply.
- Distribution Circuits - Distribution circuits that start at a DSS line usually do so through a pole mounted recloser or padmounted switch.
- Inter-station Ties - These are lines from one supply station to another to provide backup capacity. These are typical installations in the Commonwealth Electric System where the stations only have one transformer or supply line.

D. Loading Considerations

Under normal configuration (all lines in service) the loads of all lines in the line group will be below the normal ratings at all times. When the load of any of the lines reaches or is expected to reach its normal rating, some relief measure should be implemented.

During a single contingency (N-1) condition, where one of the lines is out of service, the load on any one of the remaining lines should not exceed its long term emergency (LTE) rating. When the load of any of the lines is expected to reach its LTE rating during a contingency, some relief measure must be implemented

E. Construction Types

The backbone of all new underground DSS lines should normally be constructed with 3-700 MCM cables but with a minimum of 3-500 MCM cables. The getaway section from the cubicle to the first manhole may be either 3-700 MCM or 3-1000 MCM depending on the station configuration and thermal loading configurations. In existing lines, there is a wide variety of sizes in use including many sizes of three conductor cable.

Any overhead lines should be constructed with a minimum of 3-336 aluminum conductors. Larger overhead wires such as 477 or 795 aluminum may be used if any underground cables do not limit the rating of the line.

Reclosers are installed on overhead DSS lines where distribution circuits originate. These are normally remote controlled units where the circuits also have remote controlled tie switches in order to restore load in the event of a DSS line outage.

Padmounted switches are often used on underground DSS lines where distribution circuits originate. These switches are also remote controlled with all load protected by current limiting fuses.

F. Protection and Relaying

Radial DSS lines are protected by a circuit breaker at the source station and either breakers, fuses or reclosers at the load points.

Distribution circuit taps are protected with reclosers or switches as indicated above.

Looped customer stations have breakers at the customer stations that are programmed to co-ordinate with the station breakers as well as the protective devices of other customers on that line so that when a fault occurs on the DSS line one of the two customer breakers will open to isolate the line and maintain power to the customer.

G. Numbering Scheme

Radial DSS lines are numbered with the station number of one of the load stations followed by a three or four digit number. For example, DSS line 506-138 starts at station 329 but supplies station 506.

Primary network feeders are numbered with the source station followed by four or more characters, the second of which is the character “N” such as 329-1N40H. This line originates at station 329 and supplies PNU 25 in the Brookline Primary Network.

There are some non-source lines that connect two customer looped stations. These lines have the number of one of the customer stations followed by two or more digits such as line 586-90 which runs from loop station 482 to loop station 419 but supplies station 586.

VIII. NETWORK SUPPLIES

A. Feeder Design

The standard sizes currently used for 13.8 kV network feeders are as follows:
250 MCM copper, single conductor, flat strap,15 kV, EPR – taps
500 MCM copper, single conductor, flat strap,15 kV, EPR – mainline
700 MCM copper, single conductor, flat strap,15 kV, EPR – mainline
There are many existing locations with other size conductors as well as installations with three conductor cables.
All feeders in the downtown Boston network area are pure network feeders and do not supply customer stations.

B. Feeder Loading

Network feeder cables typically have normal ratings from 200 amperes to 400 amperes depending on cable size and duct configuration. All feeders have long-term emergency (LTE) ratings that are typically 20% to 50% above the normal rating. During normal operating periods, the load should not exceed the normal rating of the cable. During a contingency condition, where an adjacent feeder is out of service, the load should not exceed the LTE rating of the cable.

C. Secondary Mains and Services

The standard sizes currently used for secondary mains are as follows:
4-500 MCM, copper, 600 volt, EP Rubber cable from the transformers to first manhole and for services from the vault to the customer.
7-4/0 AWG, copper, 600 volt, EPR Rubber cable from the transformers to first manhole, for services from the vault to the customer and for services from the secondary mains in the street.
3-#4 cables for small services
4-1/0 cables for customer services
4-4/0 cables for customer services

D. Secondary Network Vaults (120/208 volt)

Public Way Units
Secondary Network Vaults (SNVs) located in the public way are located in sidewalk vaults and typically have only one transformer. They all have ties to the secondary grid.

Private Property Units
Secondary Network vaults located on private property have the same size units but may have two or more of each unit in the vault depending on load requirements. These units typically have ties to the street mains.

Transformers and Protectors
The standard size Secondary Network Vault (120/208 volt) units are as follows:

- 1-500 kVA transformer with 1600 ampere protector
- 1-750 kVA transformer with 3000 ampere protector
- 1-1000 kVA transformer with 3000 ampere protector

E. Tertiary Network Vaults (277/480 volt)

Normal Configuration: The normal configuration of a tertiary network vault (TNV) consist of two or more of the following units located in a vault on customer property:

- 1000 kVA transformer with 1600 ampere protector
- 1500 kVA transformer with 3000 ampere protector
- 2000 kVA transformer with 3000 ampere protector
- 2500 kVA transformer with 3500 ampere protector

Contingency (N-1) Configuration: All TNVs are sized to withstand the loss of any individual feeder or transformer and still support the customer load.

F. Remote Monitoring Systems

A Remote Monitoring System originally designed by the Hazeltine Company is used to monitor load and operating status of the network units. This is accomplished with remote transmitters at each transformer and a receiver located in each network station. The following information is provided using a telephone line:

- Protector status (open or closed)
- Percent transformer loading-all 3 phases
- Voltage

Over 1000 units are currently installed and all new vaults are installed with transmitters. An additional 100 units year are installed each year until the system is fully monitored.

G. Protection and Relaying

Transformers have overload ratings above their normal rating.
Protectors have no overload rating but are sized to have a rating higher than transformer to which attached.
Protectors open automatically if load current flows from the secondary to the transformer. They DO NOT open for faults on the secondary grid.

H. Numbering Scheme

All network feeders are numbered starting with the source station and ending with the grid designation where applicable. In addition, the first digit after the letter "N" designates the bus section from which it is supplied. For example, feeder 53-1N62E originates from Station 53, bus section #6 and supplies load in the East grid.

IX. IMPROVEMENT SYSTEMS & PROGRAMS

A. Cable Cure – URD cable life extension program where a silicon gel is injected into the cable to mitigate cable treeing. URD areas experiencing multiple cable failures where the neutral is still in good condition and the number of splices is low are targeted for this program.

B. Cable Wise – A pilot program is under way investigating the effectiveness of this new technology. The technology consists of placing a low frequency on the cable while still energized and locating points of partial discharge, both with joints and cable sections. Several distribution system supply (DSS) lines were targeted in the first phase of the program and the second phase involves some testing of network feeders. The initiative results have shown this technology to be effective in locating joints in poor condition, which would have ultimately failed.

C. Overhead Circuit Reliability Program – Approximately 40 poor performing 15/25kV circuits are selected each year for this program. The program consists of the following major activities:

- The circuit receives a pole by pole walkdown to identify needed repair and upgrade work including:
  - Engineering circuit design review and field review after upgrade is completed
  - Installing additional lightning arresters and replacing older style arresters
  - Installing additional animal protection
  - Reconductoring sections of wire with multiple splices
  - Replacing old, worn cutouts
  - Installing fuses as necessary on all lateral taps
  - Replacing main line hot line clamps with new wedge style connectors and stirrups
  - Transformers in poor condition are replaced
- The circuit is tree trimmed and hazard tress are also removed
- All poles on the circuit are inspected and replaced as necessary
- A mid-point and tie radio controlled automatic sectionalizing switches are installed as necessary

D. Infrared Surveys – An infrared survey is conducted annually on the overhead main line sections of all distribution circuits.